

Effects of Multiple Applications of Simulated Quinclorac Drift Rates on Tomato

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Quinclorac drift has been speculated as the cause of injury to tomato crops throughout northeast Arkansas. In this study, we set out to determine whether tomato plant injury and yield reduction were correlated with simulated quinclorac drift. Experiments were carried out at Fayetteville, AR, in 1999 and 2000. Maximum plant injury (visual ratings) was about 20% when plants were treated with one, two, or three quinclorac applications (weekly intervals beginning at first flower) at $0.42 \text{ g ai ha}^{-1}$ (0.001 times the normal use rate to simulate drift). Maximum plant injury ranged from 48 to 68% with quinclorac simulated drift treatment of 42 g ha^{-1} . Overall, increasing quinclorac rate and number of applications increased tomato injury. In both years, tomato plant fresh-weight accumulation was not influenced by one, two, or three applications of quinclorac at 0.42 g ha^{-1} compared with the untreated control. In 1999, increasing the rate of quinclorac from 0.42 to 4.2 g ha^{-1} reduced plant fresh-weight accumulation. In 2000, there was no significant difference in plant fresh weight when plants were treated with quinclorac at 2.1 to 4.2 g ha^{-1} . Evaluation of the herbicide rate effect indicated that quinclorac at 0.42 g ha^{-1} did not reduce tomato fruit yield (total weight of edible fruit) compared with the untreated control, but yield decreased as rate increased above 0.42 g ha^{-1} . Increasing the number of applications generally decreased tomato yield, and overall as maximum visual plant injury increased, tomato yield reduction also increased linearly. We conclude that quinclorac at simulated drift rates can adversely affect tomato plant growth and yield.

Nomenclature: Quinclorac; tomato, *Lycopersicon esculentum* Mill.

Key words: Herbicide drift, auxinic herbicide, epinasty.

Tomatoes are grown on about 500 ha in Arkansas, producing an average yield of about 25 metric tons (MT) ha^{-1} , which places Arkansas thirteenth in tomato production in the United States (AASS 2003). Although relatively few hectares of tomatoes are grown commercially in Arkansas, tomatoes are economically important and accounted for over \$14.7 million in revenue in 2002 (AASS 2003).

Two major regions of commercial tomato production are in Bradley and Poinsett counties in northeast Arkansas. In field crop production areas, tomatoes are susceptible to off-target drift from pesticides aerially applied. Tomato producers in Poinsett County have reported abnormalities in their crops and believe this damage is caused by quinclorac drift from rice (*Oryza sativa* L.) fields (Anonymous 1996). However, there is no conclusive evidence to explain why this problem occurs so frequently.

Every year in Arkansas, herbicides are applied to many hectares of rice using aerial application. This method of application is preferred over ground applications because of the ability of aerial application to cover many hectares in a short time. Also, aerial application is not impeded by the presence of levees in rice fields throughout the Mississippi Delta region of Arkansas. Many rice and soybean [*Glycine max* (L.) Merr] herbicides are applied in early May to late June throughout Arkansas. During this time, weather conditions are generally unpredictable, and high wind velocity, high temperature, and low relative humidity (RH) are common. These conditions have been shown to be favorable for pesticide drift (Akersson and Yates 1987).

In 2000, quinclorac was applied to approximately 25% and 18% of the total U.S. and Arkansas rice acreage, respectively (USDA–NASS 2001). Quinclorac is widely used because it is

efficacious toward many problem weeds in rice (Stauber et al. 1991; Street and Mueller 1993; Zwick et al. 1987) and can be applied throughout the growing season (Eastin 1989). Tomato plants are extremely sensitive to quinclorac (De Barreda et al. 1993; Grossmann 1998), and growers feel that extensive use of this herbicide, coupled with a large potential risk of drift from aerial application (Barrentine and Street 1993; Sciumbato et al. 2005), has resulted in repeated damage to their tomato crops (Bansal et al. 1999).

Long-range drift of pesticides occurring at the time of application has been evaluated with carbofuran using high-volume air sprayers (Hall et al. 1997). Carbofuran applied to control alfalfa (*Medicago sativa* L.) weevils was detected in air samples from sites nearly 16 km away. Another study indicated that airborne residues of methyl parathion, molinate, and thiobencarb used on rice in the Sacramento Valley, CA, were detected in samplers installed on rooftops of public buildings in four nearby towns (Seiber et al. 1989). Residue recovery correlated well with the reported chemical use in the vicinity. Studies also indicate that dry herbicide formulations have a greater potential for drift than emulsions (Sciumbato et al. 2005). Quinclorac is a dry-formulated herbicide, thus drift potential may be greater than the previously mentioned herbicides. This indicates that there is potential for off-target movement of quinclorac spray particles.

Damage from auxinic herbicides to nontarget species has also been attributed to off-target vapor drift (Behrens and Lueschen 1979; Breeze and van Rensburg 1992; van Rensburg and Breeze 1990). Although volatilization can be a factor influencing off-target drift of many formulated auxinic-type herbicides, it is not believed to be a factor with regard to quinclorac drift because of the relatively low vapor pressure of quinclorac ($1 \times 10^{-7} \text{ mm Hg}$ at 25°C) (Vencill 2002). The possible mechanisms of quinclorac movement to nontarget areas may include direct liquid droplet, particle drift, or attachment to soil particles moved by strong winds.

Bansal et al. (1999) evaluated injury from suspected quinclorac drift on five tomato fields in the Mississippi Delta

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region of Arkansas. Plants at all sites had varying degrees of abnormal growth symptoms from the second or third week of May until harvest. The most common symptoms were severe epinasty (leaf curling and cupping), small plant size, lack of vigor, bloom abscission, and reduced fruit set and growth. At some sites, fruit set on the first flower clusters was adequate; however, fruit set on secondary clusters was poor because of excessive flower abscission. Many foliar symptoms were consistent with those caused by auxinic-type herbicides, such as quinclorac.

Much of the observed herbicide injury on tomato plants is assumed to be caused by quinclorac drift; however, tomatoes are very sensitive to many other auxinic herbicides (Zimmerman et al. 1953). Other auxinic-type herbicides (2,4-D and triclopyr) can also cause epinasty of tomato stems and leaves, making it difficult to distinguish injury symptoms among the various auxinic-type herbicides (Talbert et al. 1994). Thus, auxinic-type herbicides other than quinclorac could be contributing to the overall injury symptoms observed by some Arkansas tomato growers.

The overall objective of this research was to evaluate the effects of simulated quinclorac drift on tomato growth and development. The specific objectives were to develop a time course of symptomology from exposure to calibrated drift rates of quinclorac on young tomato plants and to evaluate the effects of multiple exposures of quinclorac on tomato growth and development.

Materials and Methods

Field studies were conducted at the Main Experiment Station in Fayetteville, AR, in 1999 and 2000 to determine the effects of quinclorac exposure on tomato growth and development. The soil was a Captina silt loam (fine-silty, mixed, mesic Typic Fragiudult) with 1.5% organic matter and a pH of 5.9. The experimental design was a randomized complete block with a factorial arrangement of treatments (quinclorac rate by number of quinclorac applications). Plots were a single row of tomatoes, 12.3 m long, 2 m between plots, a 6-m-wide alley separating replications, and four replications each year.

Each year, the test site was fertilized in the spring according to soil test recommendations, followed by planting. In 1999, tomato seeds (variety 'Mountain Supreme')¹ that were planted in a greenhouse on April 30 emerged on May 3, and plants were transplanted into the field on June 4. In 2000, tomato seeds that were planted in a greenhouse on April 20 emerged on April 24, and plants were transplanted into beds on May 24. Each plant was spaced 0.45 m apart within each row, and drip-line irrigation was used throughout the growing season. Primary weed control was achieved with sethoxydim (0.22 kg ai ha⁻¹) and metribuzin (0.56 kg ai ha⁻¹) as a broadcast treatment after plants were established. Weeds not controlled by the herbicides were removed manually. The fungicide azoxystrobin and the insecticide lambda-cyhalothrin were used throughout the season to control disease and insect pests.

Formulated quinclorac² was applied initially as plants began to flower. This timing was chosen because studies have indicated that drift applications to tomato at or just before bloom were the most detrimental to yield (Gilreath et al. 2001a; Romanowski 1980). In 1999, quinclorac was applied

at 0.42, 4.2, and 42 g ai ha⁻¹, but in 2000, rates were adjusted to represent lower drift rates, i.e., applications were 0.42, 2.1, and 4.2 g ai ha⁻¹. Each quinclorac rate was applied at either midbloom of the first flower cluster, midbloom of the first cluster followed by another application 1 wk after initial treatment (WAT), or midbloom of the first cluster followed by applications at 1 and 2 WAT. The herbicide was applied in a 60-cm band over-the-top of plants using a one-nozzle CO₂ backpack sprayer, equipped with an 8003 even flat-fan nozzle, and calibrated to deliver 187 L ha⁻¹ of water at 172 KPa. All treatments were made at 6:00 A.M. with zero wind velocity. Applications were initiated July 12 and July 11 in 1999 and 2000, respectively. Ambient air temperatures ranged from 20 to 25 °C, RH ranged from 85 to 95%, soil temperatures ranged from 20 to 25 °C, and adequate soil moisture existed at all application times.

Tomato response was recorded at 3, 7, 10, 14, 17, 21, 28, 35, 42, and 49 d after initial treatment (DAT) of quinclorac. Symptoms used to estimate tomato damage included observing various parameters: leaf curling, epinasty, stunting, and biomass reduction compared with an untreated control. Each rating value was an estimated percentage of injury based on overall tomato injury symptoms, with 0% equal to no injury and 100% equal to plant mortality. Single random plants were harvested from each plot at 0, 3, 7, 10, 14, 17, 21, 28, 35, 42, 49, and 56 DAT by excising the plant at the soil surface and determining the fresh weight. When fruits began to develop, they were included in the total fresh weight.

Tomato yield was determined by harvesting all ripe tomatoes from a subplot 3-m long, where no tomato plants had been sacrificed, for tomato fresh-weight determination. In 1999, the fruits were harvested August 27, September 3, and September 10, and in 2000, fruits were harvested August 22, August 30, and September 8. Fruit was determined to be mature when it had developed red pigmentation, and only mature fruit was harvested.

Data Analysis. Tomato injury and yield were subjected to ANOVA, and means were separated using Fisher's Protected LSD test at the 5% probability level. A different ANOVA test was conducted for each data collection interval (0, 3, 7, 10, 14, 17, 21, 28, 35, 42, and 49 DAT). Common treatments of 0.42 and 4.2 g ha⁻¹ applied one, two, and three times were initially analyzed together over years to evaluate the effect of year within the combination of rates and number of applications. In the final analysis, years were analyzed separately because of a significant interaction that existed between year, herbicide, and number of applications, as well as the lack of homogeneity of treatments among years. Analyses were conducted using PROC MIXED in SAS.³

Within each year, quinclorac rate interacted with number of applications for injury data; so rate and number of applications are presented separately. For yield data, no interaction existed between rate and number of applications; thus, only main effects are discussed. Regression analysis for plant fresh-weight accumulation and the dose-injury response model was conducted using fit of least squares in SAS.

Results and Discussion

Tomato Injury. No injury symptoms were detected on untreated tomato plants in either year indicating no off-target

Table 1. Interaction of quinclorac rate and number of applications on tomato plant injury, Fayetteville, 1999 and 2000.

		Tomato plant injury, days after initial treatment													
		1999							2000						
Rate	Application no. ^a	7	14	21	28	35	42	49	7	14	21	28	35	42	49
g ai ha ⁻¹		%													
0.42	1	0	4	5	5	5	4	4	0	2	3	3	2	0	0
	2	0	8	15	14	13	11	9	0	4	5	4	3	3	0
	3	0	10	19	21	18	14	13	0	4	7	8	6	5	3
2.1	1	—	—	—	—	—	—	—	4	8	10	8	6	5	3
	2	—	—	—	—	—	—	—	4	14	20	19	16	13	8
	3	—	—	—	—	—	—	—	5	17	28	32	28	21	15
4.2	1	5	25	38	36	34	29	25	3	18	32	28	21	18	11
	2	8	30	48	46	44	46	43	5	26	43	41	35	29	20
	3	5	32	55	59	53	50	45	5	28	47	49	41	34	28
42	1	25	36	43	48	48	45	45	—	—	—	—	—	—	—
	2	24	49	53	56	55	53	52	—	—	—	—	—	—	—
	3	20	49	66	68	64	61	59	—	—	—	—	—	—	—
LSD (0.05)		5	5	7	5	4	5	5	2	3	4	4	5	4	3

^a One application signifies tomato plants were sprayed at first bloom, two applications signify plants were sprayed at first bloom followed by another application 1 wk later, and three applications signify plants were sprayed at first bloom followed by two additional applications at weekly intervals.

movement of quinclorac was occurring from plot to plot by drift or vapor. Tomato injury was 5% or less with 0.42 g ha⁻¹ (0.001 times the labeled rate for rice) applied once, regardless of year (Table 1). This rate caused slight epinasty in meristematic regions and stem twisting, but stunting and biomass reduction did not occur (Figure 1). In 1999, two applications of quinclorac at 0.42 g ha⁻¹ resulted in more injury than a single application at this rate, and a third application caused still greater injury (Table 1). In 2000, injury from two applications of quinclorac at 0.42 g ha⁻¹ was not different from a single application at this rate, but three applications generally increased injury above that of single application. Increased injury from multiple applications was expressed as greater leaf curling of new growth, stem bending, stunting, and biomass reduction. Multiple drift rate applications of 2,4-D and dicamba (other auxinic-type herbicides) have been shown to increase injury above a single drift rate application in another Solanaceae plant, pepper (*Capsicum annuum* L.) (Gilreath et al. 2001b). Our data show that maximum injury from multiple applications of quinclorac at 0.42 g ha⁻¹ was 21% in 1999 and 8% in 2000. Reduced injury in 2000 compared with 1999 may have been caused by rainfall that occurred soon after the second and third applications in 2000 (Figure 2). Rainfall could have washed some quinclorac from the leaves, thereby limiting uptake and injury. Furthermore, plants treated with quinclorac at 0.42 g ha⁻¹ did not display injury at the end of the growing season (Table 1).

In 2000, plants treated with quinclorac at 2.1 g ha⁻¹ (0.005 times the labeled rate for rice) exhibited more injury than plants treated with 0.42 g ha⁻¹ (Table 1). Growth abnormalities on tomato plants treated with 2.1 g ha⁻¹ (image not shown) were similar to, but more severe than, plants treated with 0.42 g ha⁻¹ (Figure 1). Plant injury from a single application at 2.1 g ha⁻¹ was restricted to growth regions, but injury became more widespread throughout new tissue as the number of applications increased. Maximum injury from plants treated with quinclorac at 2.1 g ha⁻¹ once and twice was 10 and 20%, respectively, and was first noticed at 21 DAT (Table 1). Maximum injury from plants treated three times was further increased to 32% at 28 DAT.

Quinclorac treatment at 4.2 g ha⁻¹ (0.01 times the labeled rate for rice) increased tomato injury compared with plants treated with 0.42 and 2.1 g ha⁻¹ (Table 1). Epinasty was more severe in the terminals and more widespread over the entire plant (Figure 1). Visual estimations of stunting and biomass reduction were also greater than in plants treated with quinclorac at 2.1 and 0.42 g ha⁻¹ (Table 1). Maximum injury from quinclorac at 4.2 g ha⁻¹ occurred at 21 DAT for plants treated once or twice, and at 28 DAT when treated three times. Injury was numerically higher in 1999 (i.e., 38% from one application to 59% from three applications) compared with 2000 (i.e., 32% from one application and 46% from three applications). Tomato injury in these experiments was greater than that reported in early fruiting cotton (*Gossypium hirsutum* L.), which exhibited only 15% injury after quinclorac treatment at 9 g ai ha⁻¹ (Snipes et al. 1992).

Quinclorac treatment at 42 g ha⁻¹ (0.1 times the labeled rate for rice) further increased tomato injury above that observed at 4.2 g ha⁻¹ (Table 1). More growth malformations, stunting, and biomass reductions were noted at the higher concentration. Maximum injury was 48, 56, and 68% when treated one, two, and three times, respectively. Maximum injury occurred 28 DAT for all plots treated with 42 g ha⁻¹. Furthermore, plants treated with 42 g ha⁻¹ did not recover to the same degree as those treated with 4.2 g ha⁻¹. Tomato injury from quinclorac at 42 g ha⁻¹ remained severe between 14 and 49 DAT.

Overall, as the rate of quinclorac increased, more severe injury symptoms were observed because of the lack of the tomato plants' ability to recover from the injury. Multiple applications of each rate caused more extensive injury to tomato plants and further limited recovery by the end of the growing season. These data are similar to the findings of Gilreath et al. (2001a), who reported that increasing drift rates and number of applications of 2,4-D and dicamba caused greater injury and reduced tomato vigor. In addition, our results indicate that the injury from drift events with similar rates can vary substantially from year to year.

Tomato Fresh Weight. In 1999, fresh-weight accumulation of untreated tomato plants was linear during the growing

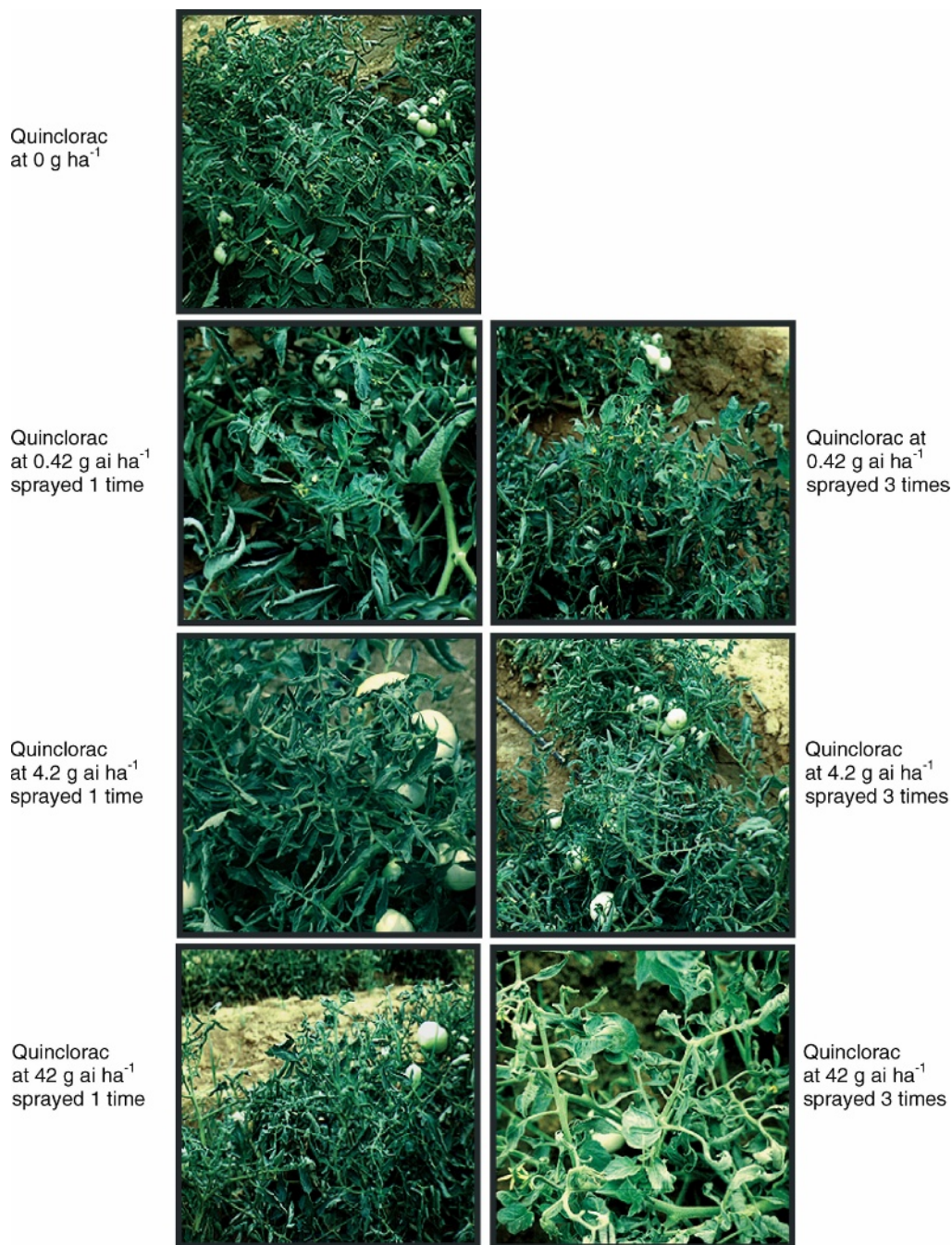


Figure 1. Photographs of tomato injury when quinclorac was applied at various rates and number of applications (pictures taken at 28 d after initial treatment).

season (Figure 3). The model for plant growth of untreated tomato plants was $Y = 0.13X + 1.9$, where Y is the predicted fresh weight and X is DAT. Plant weights averaged $1.9 (\pm 0.30)$ kg plant⁻¹ when treatment of herbicide began, and accumulated fresh weight at a rate $0.13 (\pm 0.01)$ kg d⁻¹. Plant fresh weight was similar over time when treated with zero, one, two, and three applications of quinclorac at 0.42 g ha⁻¹ (Figure 3a). Tomato plants treated with 0.42 g ha⁻¹ continued to accumulate fresh weight during the growing season at a rate similar to the untreated control. In 1999, when quinclorac rate was increased to 4.2 g ha⁻¹, fresh-weight accumulation rate was reduced (Figure 3b). Tomato plants treated with 4.2 g ha⁻¹ quinclorac accumulated 0.06 kg fresh weight d⁻¹. Multiple applications of

quinclorac at 4.2 g ha⁻¹ caused no change in fresh-weight accumulation compared with a single application. The highest rate of quinclorac (42 g ha⁻¹) caused the greatest decrease in fresh-weight accumulation (Figure 3c). Fresh-weight accumulation was similar to the untreated control through 14 DAT but then began to decline. Plants partially recovered from injury by producing new growth. Treatment with 42 g ha⁻¹ quinclorac caused a 50% plant biomass reduction compared with the untreated control by the end of the growing season.

In 2000, overall tomato fresh weights were less than those observed in 1999 (Figure 3 vs. 4). In 2000, fresh-weight accumulation of untreated plants could be described by a quadratic model (Figure 4). The model for untreated tomato fresh-weight accumulation was $Y = 0.15X - 0.001X^2$

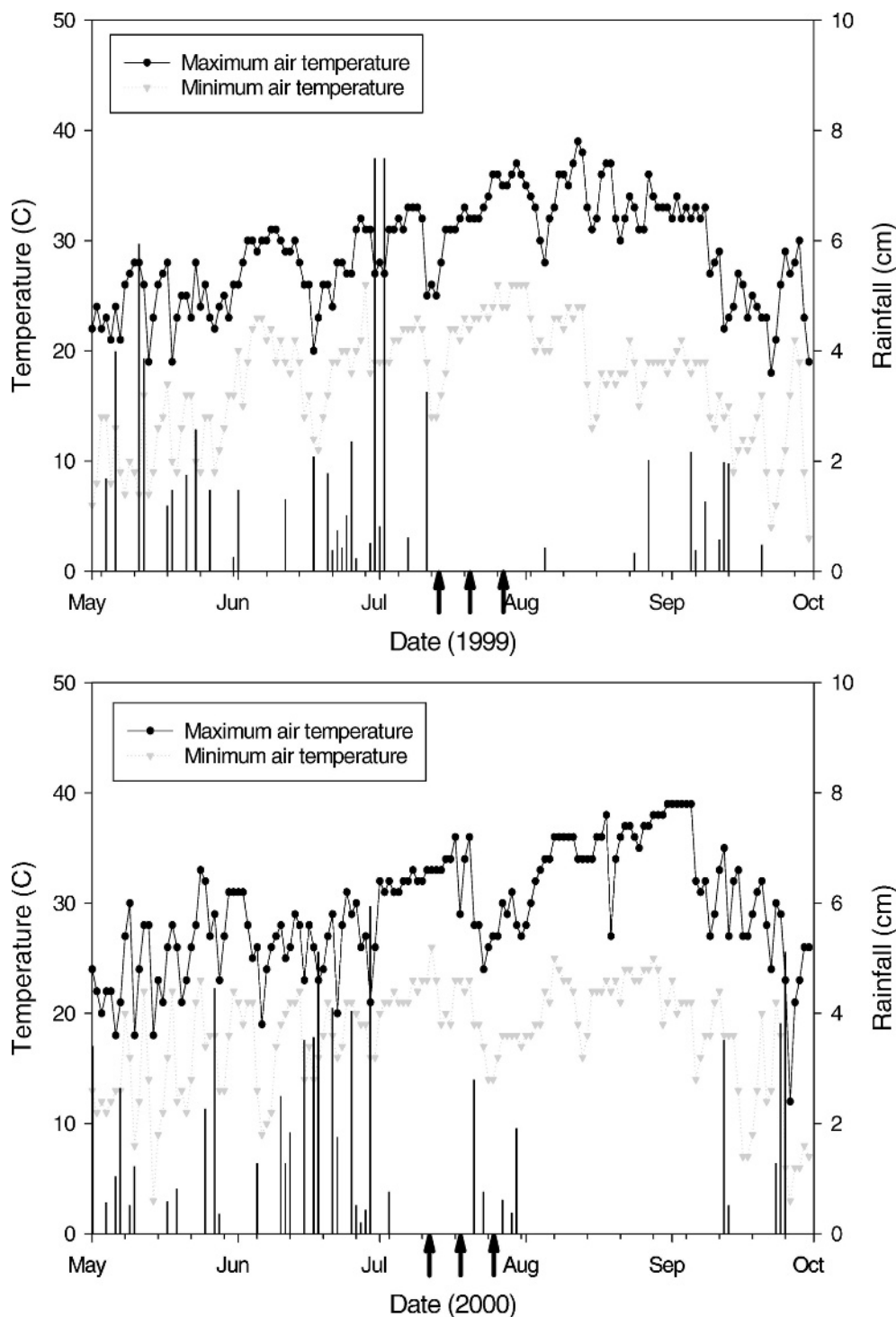


Figure 2. Air temperature and rainfall for the 1999 and 2000 growing seasons. Arrows on each graph indicate the approximate application times of quinclorac to tomato plants.

+ 1.21, where Y is fresh-weight accumulation and X is DAT. This model suggests that plant size was similar when treatments began in both years (Figure 3 vs. Figure 4). Initially, plant fresh-weight accumulation was also similar (0.12 kg d^{-1} in 1999 compared with 0.15 kg d^{-1} in 2000), but in 2000, this parameter was reduced later in the growing season compared with 1999.

In both years, plant fresh weight after treatment with one, two, and three applications of quinclorac at 0.42 g ha^{-1} was similar to the untreated control over time (Figure 3a vs.

Figure 4a). Although some growth abnormalities were observed, overall fresh-weight accumulation was not influenced. In 2000, tomato plants treated with quinclorac at 2.1 g ha^{-1} accumulated fresh weight linearly (Figure 4b), which differed from the untreated plants and plants treated with 0.42 g ha^{-1} (Figure 4a). Plant fresh-weight accumulation ranged from 0.06 to 0.07 kg d^{-1} after treatment with quinclorac at 2.1 g ha^{-1} (Figure 4b), which was less than the initial fresh-weight accumulation of untreated tomato plants (0.15 kg d^{-1}). Fresh-weight accumulation in plants treated

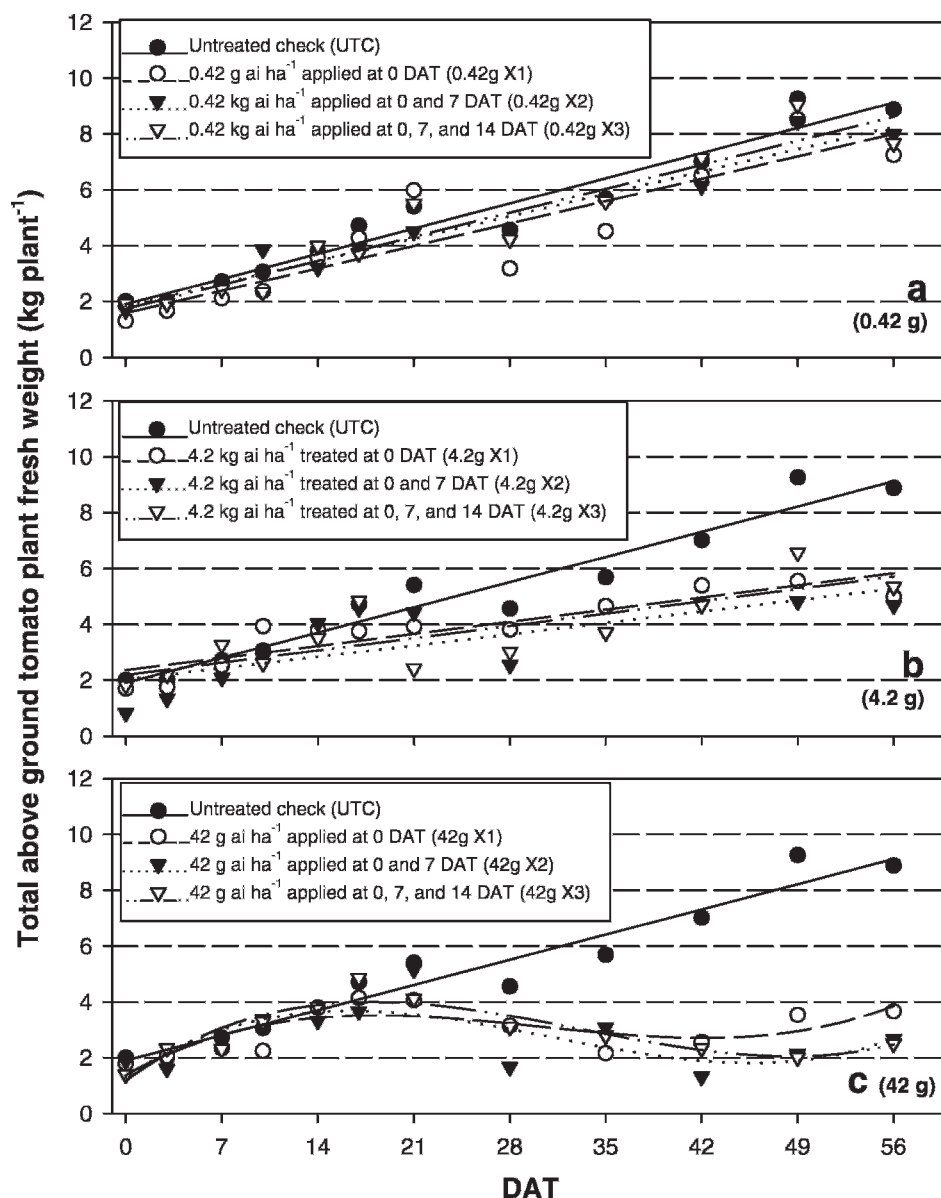


Figure 3. Best fit and means of tomato plant fresh-weight accumulation as influenced by quinclorac application rate and number of applications in 1999. Plant fresh weight accumulation models for plants treated with quinclorac at (a) 0.42 g ai ha⁻¹, (b) 4.2 g ai ha⁻¹, and (c) 42 g ai ha⁻¹ either one (X1), two (X2), or three (X3) times compared to an untreated check (UTC). Estimates of the predicted models with standard errors in parentheses (X = days after initial treatment; Y = total above ground tomato fresh weight [kg plant⁻¹]): UTC, $Y = 0.13(0.010)X + 1.90(0.30)$, $R^2 = 0.94$; 0.42 g X1, $Y = 0.11(0.017)X + 1.58(0.51)$, $R^2 = 0.82$; 0.42 g X2, $Y = 0.11(0.008)X + 1.85(0.25)$, $R^2 = 0.95$; 0.42 g X3, $Y = 0.12(0.012)X + 1.74(0.37)$, $R^2 = 0.91$; 4.2 g X1, $Y = 0.06(0.010)X + 2.36(0.29)$, $R^2 = 0.80$; 4.2 g X2, $Y = 0.06(0.016)X + 2.02(0.29)$, $R^2 = 0.65$; 4.2 g X3, $Y = 0.06(0.014)X + 2.18(0.42)$, $R^2 = 0.66$; 42 g X1, $Y = 0.27(0.081)X - 0.01(0.004)X^2 - 0.0001(0.00001)X^3 + 1.38(0.48)$, $R^2 = 0.63$; 42 g X2, $Y = 0.33(0.117)X - 0.01(0.005)X^2 - 0.0001(0.00001)X^3 + 1.29(0.69)$, $R^2 = 0.58$; 42 g X3, $Y = 0.36(0.061)X - 0.01(0.003)X^2 - 0.0001(0.00001)X^3 + 1.18(0.36)$, $R^2 = 0.84$.

with quinclorac 2.1 g ha⁻¹ was less than the untreated control throughout much of the growing season but equal to the untreated control by the end of the growing season. Significant injury was correlated with each quinclorac application at 2.1 g ha⁻¹, but the tomato plants recovered from the initial injury (Table 1), which allowed the tomato plants to continue accumulating fresh weight.

In 2000, fresh-weight accumulation of plants treated with 4.2 g ha⁻¹ (Figure 4c) was similar to that in plants treated with 2.1 g ha⁻¹ (Figure 4b). Plants treated with 4.2 g ha⁻¹ accumulated 0.07 kg of fresh weight d⁻¹. Plants treated with quinclorac at 4.2 g ha⁻¹ were smaller than untreated plants over the growing season, but no differences in fresh weight were detected by the end of the

growing season. Three quinclorac applications at 4.2 g ha⁻¹ were more injurious than one or two applications and resulted in reduced fresh weight throughout the season.

Tomato Yield. Analysis of yield data within each year indicated no herbicide-rate interaction with number of applications, therefore, only main effects are discussed. Maximum yields were 20.6 and 18.7 MT ha⁻¹ in 1999 and 2000, respectively, in plots not treated with quinclorac (Table 2). Evaluation of rate main effects indicated that yield from plants treated with 0.42 g ha⁻¹ was not different from the untreated control in either 1999 or 2000. Although some injury was noted on plants treated with 0.42 g ha⁻¹ (Table 1), these plants overcame the injury, and yield was

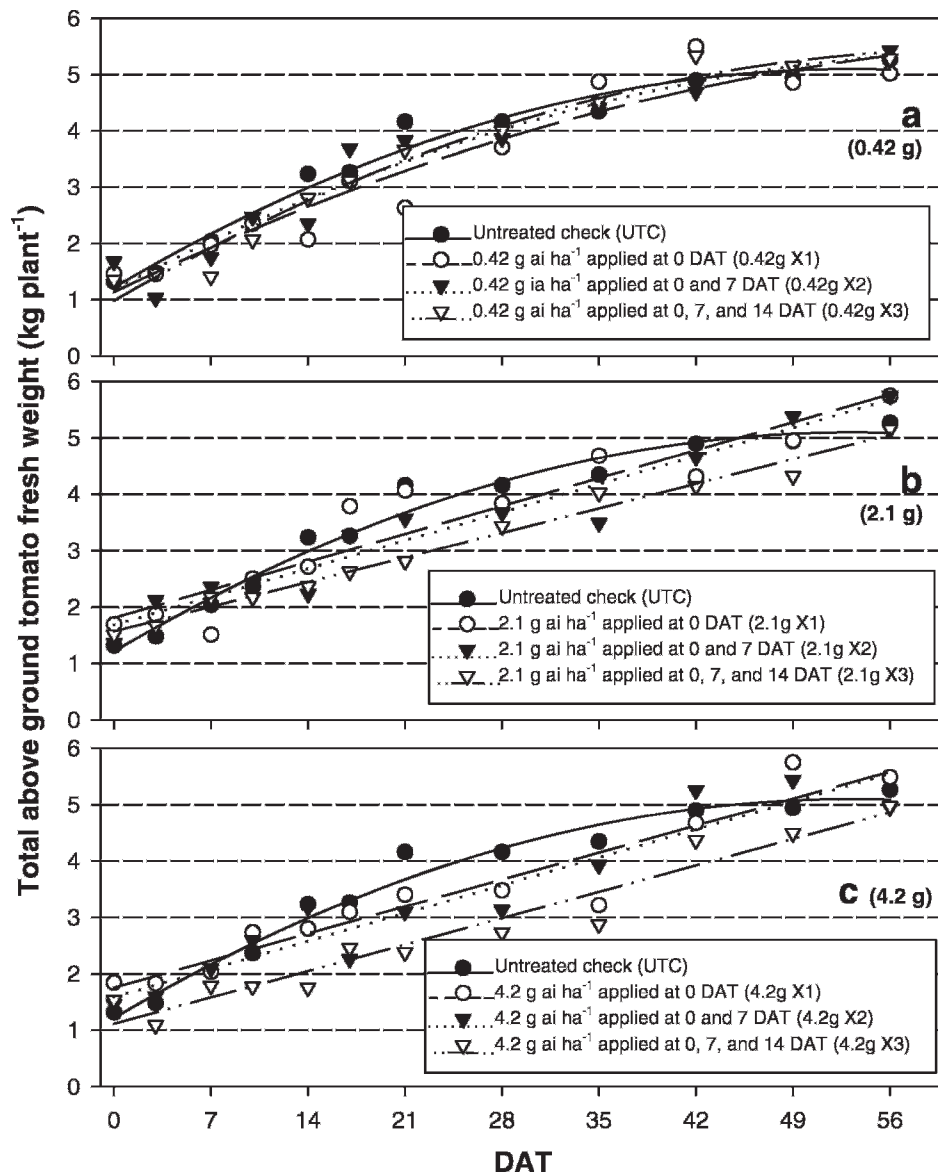


Figure 4. Best fit and means of tomato plant fresh-weight accumulation as influenced by quinclorac application rate and number in 2000. Plant fresh weight accumulation models for plants treated with quinclorac at (a) 0.42 g ai ha⁻¹, (b) 2.1 g ai ha⁻¹, and (c) 4.2 g ai ha⁻¹ either one (X1), two (X2), or three (X3) times compared to an untreated check. Estimates of the predicted models with standard errors in parentheses (X = days after initial treatment; Y = total above ground tomato fresh weight [kg plant⁻¹]): UTC, $Y = 0.15(0.01)X - 0.001(0.0003)X^2 + 1.21(0.16)$, $R^2 = 0.98$; 0.42 g X1, $Y = 0.12(0.03)X - 0.001(0.0005)X^2 + 1.13(0.31)$, $R^2 = 0.92$; 0.42 g X2, $Y = 0.13(0.02)X - 0.001(0.0004)X^2 + 1.18(0.26)$, $R^2 = 0.94$; 0.42 g X3, $Y = 0.14(0.02)X - 0.001(0.0003)X^2 + 0.98(0.18)$, $R^2 = 0.97$; 2.1 g X1, $Y = 0.07(0.008)X + 1.81(0.23)$, $R^2 = 0.89$; 2.1 g X2, $Y = 0.07(0.006)X + 1.68(0.17)$, $R^2 = 0.94$; 2.1 g X3, $Y = 0.06(0.002)X + 1.57(0.07)$, $R^2 = 0.99$; 4.2 g X1, $Y = 0.07(0.006)X + 1.76(0.19)$, $R^2 = 0.92$; 4.2 g X2, $Y = 0.07(0.007)X + 1.59(0.21)$, $R^2 = 0.91$; 4.2 g X3, $Y = 0.07(0.005)X + 1.11(0.15)$, $R^2 = 0.94$.

not adversely affected (Table 2). Quinclorac levels above 0.42 g ha⁻¹ reduced tomato yield, and increased rates caused decreased yields. Hemphill and Montgomery (1981) found that small increases in the yield of peppers from plants treated with 2,4-D at 2.1 g ha⁻¹ were due to increased plant branching, but no such increases in yield or branching were observed in tomato plants treated with quinclorac. Gilreath et al. (2001a), found that tomato plants could withstand some levels of injury from drift rates of a nonauxinic herbicide (glyphosate) without reducing yield. Our results with quinclorac on tomatoes are somewhat similar to this latter report.

Yield was not delayed in either year because of drift at 0.42 g ha⁻¹ compared with the untreated control (data not shown). In 1999, 47% of the tomato yield was harvested on

the first harvest date from the untreated tomato plots compared with 49% on the first harvest date from plots treated with quinclorac at 0.42 g ha⁻¹ (data not shown). In 2000, 42% of the tomato yield was harvested from the untreated control on the first harvest date compared with 45% on the first harvest date when plots were treated with 0.42 g ha⁻¹ (data not shown).

Evaluation of application main effects indicated that a single quinclorac application reduced yield in 1999 compared with the untreated control, but a single application did not affect yield in 2000 (Table 2). In both 1999 and 2000, two applications of quinclorac reduced yields compared with the untreated control, but yields were not different from a single application of quinclorac. In peppers, a Solanaceae crop similar to tomatoes, two applications of 2,4-D or dicamba

Table 2. Effects of quinclorac rate and application number on tomato fruit yield, Fayetteville, 1999 and 2000.

Quinclorac rate ^b	Tomato fruit yield ^a	
	1999	2000
g ai ha ⁻¹	MT ha ⁻¹	
0	20.6	18.7
0.42	18.7	17.3
2.1	-	14.4
4.2	7.9	11.6
42	2.3	-
LSD(0.05)	2.0	2.5
Applications ^{c,d}	MT ha ⁻¹	
No.		
0	20.6	18.7
1	10.9	16.7
2	9.7	14.8
3	8.3	11.8
LSD(0.05)	2.0	2.5

^a Yield is a cumulative total of three harvests in both 1999 and 2000. Yield is expressed in metric tons (MT) ha⁻¹.

^b Quinclorac rate was pooled over 1, 2, and 3 applications.

^c One application signifies tomato plants were sprayed at first bloom, two applications signify tomato plants were sprayed at first bloom followed by another application 1 wk later, and three applications signify tomato plants were sprayed at first bloom followed by two additional applications at weekly intervals. Applications were pooled over quinclorac rate.

^d 1, 2, and 3 applications were pooled over quinclorac rate.

caused no more yield reduction than a single application (Gilreath et al. 2001b). Our data showed that three quinclorac applications reduced yields compared with a single quinclorac application in 1999 but did not differ from two applications. In 2000, three quinclorac applications reduced yields compared with both one and two applications.

Overall, if tomatoes receive low drift levels of quinclorac resulting in injury, yield reductions are not necessarily expected. Plants may be able to recover from a single occurrence of drift at low levels, but if multiple drift incidents occur, yield reduction is more likely.

Data Relationships. A relationship between tomato yield and maximum visual tomato injury was established to predict yield losses from visual injury (Figure 5). The model for predicting yield loss from maximum tomato injury during the growing season is

$$Y = -8.35 + 1.37X \quad [1]$$

where Y is equal to the expected percent yield loss, and X is equal to the maximum tomato injury (%) observed during the growing season. From our data, the model indicates that greater than 6% maximum injury must occur during the season before yields are reduced. Furthermore, each 1% increase in injury above 6% injury will relate to a 1.37% ($\pm 0.02\%$) reduction in tomato yield. Finally, the model predicts that 79% maximum injury during the season would reduce tomato yield to zero.

The model serves only as a predictor based on yield and injury observations that we collected over 2 yr at a single location. As we have seen in our experimental plots, environmental conditions can change drastically on a yearly basis. Also, our estimations of maximum injury could differ from others who may use the model. Thus, this model may not precisely predict yield loss for another individual in another year and location. Although the strength of this

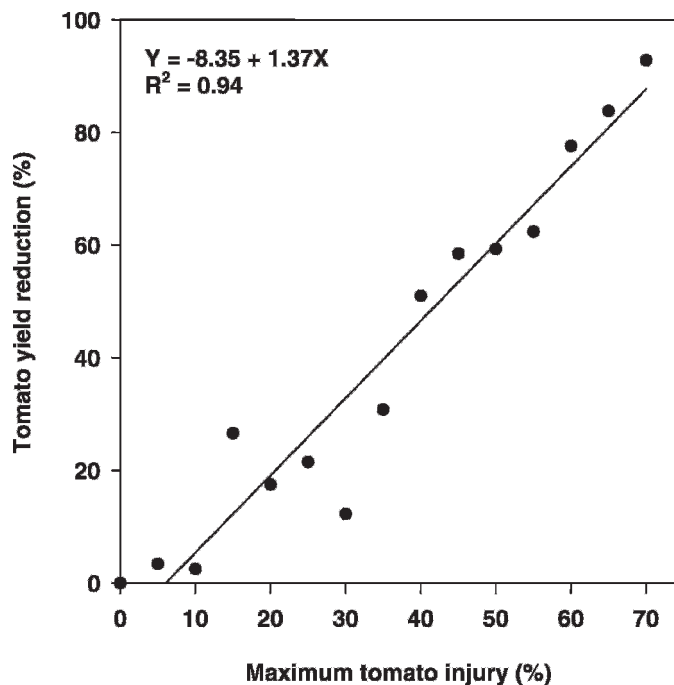


Figure 5. Yield reduction as influenced by maximum tomato injury. Correlation is a combination of data collected in 1999 and 2000. Maximum injury generally occurred at 21 to 28 d after initial application (DAT). Y = predicted yield reduction; X = maximum tomato injury.

model is not its preciseness, it provides a tool for extension agents or farmers that give an idea of what to expect when injury is observed. For example, if an estimation of 10% maximum injury is observed over a field, a farmer could expect about a 5% yield loss. If maximum injury was estimated at 25%, a farmer could expect about a 25% yield loss. The expected yield loss could then dictate a farmer's management decisions. If yield loss is expected to be low, a farmer may not change his or her input strategies. If yield loss is expected to be high, the farmer may wish to reduce inputs into the crop and save money and resources. Although the model is precise in nature, it can also be used as a tool for estimating yield loss, thus aiding in management decisions.

In conclusion, quinclorac drift and subsequent injury to tomatoes throughout Arkansas has been documented (Bansel et al. 1999). Although quinclorac drift has been an ongoing problem for tomato growers in Arkansas, no research had previously been done to address the problem. This article clearly shows that simulated quinclorac drift causes symptoms on tomato plants and that injury associated with simulated quinclorac drift can reduce yields. We have had the opportunity to observe only a few of the production fields that were supposedly injured by quinclorac drift; therefore, it was difficult to understand the magnitude of the problem. Also, we were not able to closely follow the crops through to harvest and do not know if the farmers put the same time, care, and resources into the damaged crops as they would have if the crops were undamaged. Because of these discrepancies, it is difficult to make comparisons between what happened in our research plots and what actually happened under specific field-production situations. In conversations with some of the tomato growers, we concluded that the tomato farmers generally felt that yield reductions would be greater than our research indicated.

This research defined the effects of quinclorac drift on growth and development of tomato plants. Injury increases as herbicide rate and number of applications increase. Lower quinclorac drift rates caused mild symptoms, but plants can recover from the slight early injury, and yield may not be affected. However, as quinclorac rate and number of applications increase, yield decreases. These data can also be used to predict tomato yield losses from maximum visual injury. The ability to predict yield losses from foliar injury observations may allow tomato producers or regulatory officials to better estimate yield losses after drift incidents, thus aiding in management decisions.

Source of Materials

¹ 'Mountain Supreme' hybrid tomato seed. Chesmore Seed Company. 5030 Highway 36 East, St. Joseph, MO 64507.

² Quinclorac (Facet 75 DF). BASF Corporation. Agricultural Products Group. P.O. Box 13528, Research Triangle Park, NC 27709.

³ SAS, version 8, SAS Institute, 100 Campus Drive, Cary, NC 27513.

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